INSTRUCTION IN SCIENCE AND ART FOR WOMEN.

NOTES

OF FIFTEEN LECTURES

ON

"PHYSICS AND CHEMISTRY,"

DELIVERED BY

PROFESSOR GUTHRIE.

IN THE

LECTURE THEATRE

OF THE

SOUTH KENSINGTON MUSEUM

DURING

JANUARY AND FEBRUARY, 1872.

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INSTRUCTION IN SCIENCE & ART FOR WOMEN.

RECAPITULATION AND GOSSIP ON THE LECTURES DELIVERED BY PROFESSOR GUTHRIE,

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AT SOUTH KENSINGTON MUSEUM.

WINTER 1871—1872.

At the end of this brief sketch of the branches of science which we have just studied, I wish shortly to recapitulate the chief facts which we have examined together by means of experiment, and to add a few remarks upon the study of physical science in its wider sense.

Limited as we have been in regard to the time at our disposal, I had at starting the choice of two methods of instruction. Comparing you, for the moment, with travellers and myself with your guide, it was in my power to take you at once as it were, to the top of a mountain and point out to you the general bearings of the several features of the land beneath us, dim in the distance: or to examine with some minuteness the windings of some particular stream, the structure of some particular formation, the fanna or flora of some particular district. That I have preferred the latter course is because I hold it to be of vastly greater avail for our present purpose. Do not, however, on that account suppose that I would discourage generalizations or discredit speculation. Even from the very beginning of our intellectual life, classification must go hand in hand with the perception of things and generalization with that of facts; otherwise we would be creatures of memory and not of memory and reason united. Still I have preferred that we should concentrate our attention on two or three principles of each chapter of the limitless subject, reflecting that although the examination of a brick may give us little idea of the architecture of a building, the examination of one house may give us a clear impression of the arrangements of another and indeed of the habits of a whole people. So now that we are in possession of a few truths concerning matter and have had our minds directed to a few principles linking these truths together, let us, to return to my simile, cease our upward toil, looking around at what we have surmounted and above at what is yet to be achieved.

I have striven to bring before you a systematic series of experiments and have strung these together on a slender thread of narrative. For the choicest words of the most skilled rhetorician are colourless and feeble compared with the eloquence of nature when she speaks with the tongue of experiment. These experiments have been so far progressive that the earlier ones have illustrated the nature of mechanical force, that force which we usually look on as the simplest. It would undoubtedly have been without use, and it would in all probability have done harm, if at starting I had tried to prove to you that mechanical force has no more title to be reckoned the simplest force than any one of the others; my endeavour would have been to show the identity of all kinds of forces with one another. We are accustomed to look upon the most familiar as the most simple. Quacks rebuke us for using such medicines as mercury, arsenic, or quinine, and taking some wayside flower or root they boil it down and call the decoction a "simple," though often the most skilful would be unable to determine the composition of the "wicked broth."

So, when we push our hand against an inkstand we see the latter move and call the action simple, though we are as far off knowing why the object pressed should move or why a stone falls to the earth as we are why smooth glass becomes positively, and rough glass negatively, electrified when rubbed with flannel.

Starting thus from mechanical force we found how completely such force may be represented by straight lines and showed the relation in size and direction of three forces keeping one another at rest, thus establishing what may be justly termed the key to all problems of equilibrium, the principle of all machines at rest. We showed how this is in perfect harmony with the strict economy of nature which is neither a niggard or a spendthrift but, is rigidly just in her accounts.

Turning to liquids we found exactly the same economy to prevail, and although we could—witness the hydraulic press—overcome a great pressure by a little one, we did not thereby any more defraud nature than does the bird which gathers with ease twig by twig from the ground to build a nest which when built is heavier than the bird can lift. The hand at the long arm of the crow-bar, the piston in the little cylinder of the press and the bird, had all to travel far: the farther the less the force which they exerted.

It was by examining the condition of equilibrium of a solid floating in or hung in a liquid that we were led to get, I hope, a clear notion of the meaning of comparative density or specific gravity. I lingered around this point because we were getting for the first time in our course the conception of the property of a mass of matter considered apart from the individual mass. An "abstract" idea, the type of many.

In considering the relation of mechanical force to gases you will remember that we first convinced ourselves that air, which we took as the representative of all gases, has weight whereby it is pressed to the earth. We measured the total weight of the air above any little spot near the earth's surface by pitting it against the weight of a column of mercury, and we thus formed a barometer. One effect of such atmospheric pressure was shown to be that the air, like a long spiral spring set on end, was crushed by its own weight. On artificially increasing the pressure, the air was shown to be still further crushed, while on removing the pressure it expanded. On studying this fact more carefully it appeared that the volume of a given quantity (weight or mass) of air varied inversely with the pressure upon it, or in other words that its density varied directly with the pressure. The picture thus formed itself in our minds that we live at the bottom of an air-ocean whose upper surface, if it have one, is at an unknown distance above us. The weight of this air gives rise to the class of phenomena which we usually call suction or drawing. Historically we have here the first instance of a supposed pulling force being found to be in reality a pushing one. It is my firm belief, although I am at present alone therein, that there is no such thing as an attractive force in nature, and that even electrical, magnetic, and ponderous tendency to approach will some day be shown to result from pressure.

The compressibility of air is the origin of sound. The bursting of a paper bag of compressed air may be looked on as the type of sound origin. A shell-like state of compression in the air spreads through the air at the rate of eleven hundred feet a second, and such a travelling state is called a wave; for as is the case with a smooth rolling wave of the sea the matter agitated does not progress. And as we never see a smooth sea surface travelled over by a single mere mountain of water, but as such a mountain is invariably followed by a valley, so in the sound wave the state of condensation is invariably followed by a state of rarefaction. When such a complete wave reaches the drum of the ear, the latter is pushed inwards and then pulled out. The effect of this motion is communicated to the auditory nerve which interprets it to the consciousness as sound. And here we are forced to admit, as we always are in approaching our senses from the external world, that many a link is wanting—links, perhaps, never to be forged. As sound is to air pulsation, so is sight to light; and although light and air throbs would exist if all living things were to perish there would then be neither sight nor sound. Just as we see the picture thrown upon the retina and can trace the fibres of the latter to the brain and yet cannot tell how light becomes sight, so we do not know how air-waves become sound. It is convenient to call an air-wave a wave of sound, but it is strictly as incorrect to call it so as it would be to call a ray of light a ray of sight, or to talk of a lump of sugar as a lump of sweetness.

It is seldom that we hear a simple sound. Even when originally simple a wave quickly dashes itself into countless fragments against surrounding objects, and though some of it may reach the ear in its original purity, the latter is speedily assailed by the quickly hatched brood of secondary waves, and a noise results. But if the origin of sound give out in quick and uniform succession, a series of similar waves or even shortly enduring noises, the mind is still feeling the impression of one while the effect of its successor is beginning to be felt, and a

streak of sound is produced just as a streak of light is formed when a bright point moves swiftly. Note is the result the pitch of which depends upon the rate of sequence of the individual sounds, and the loudness upon the violence of each throb.

Sound stands somewhat in the same relation to heat as the waving to and fro of a poplar stands to the rustling of its leaves. Our minds are getting more and more accustomed to recognise continuity in the universe, and to find analogies between the vast and the minute. The heavenly bodies in their orbits are types of the particles of matter which we can handle. Call these small parts particles if you please, or call them molecules, but do not call them atoms: do not write "*finis*" to the book of nature. Anything which sets these particles in more rapid motion amongst one another causes the body which they constitute to become warmer. Nay, most philosophers say that that molecular motion *is* heat. The orbit of each particle being thus increased, the whole body increases in size,—expands by heat. The very force which the heat-receiving body exercises in its effort to expand consists of the force of the blows which its particles give upon the constraining body. Rub two sticks together and you set their particles vibrating in larger orbits: rub the sticks still more and some of their particles dance off with the particles of oxygen in the air and the sticks burn.

As agitation in one part of a crowd spreads through the crowd, so heat travels from place to place in matter, diminishing in intensity as it recedes from the heat-origin because the same quantity of momentum has to be distributed over a larger number of particles.

The capacity which different substances have for heat may be compared to, or rather is, their molecular inertia: and as a mass of matter absorbs work when being set in motion and gives out the same quantity when being brought to rest, so the heat given out by a body when it cools from 100° to 0° C. is precisely equal in amount to the heat which the body absorbed when it was heated from 0° to 100° C. The molecular momentum is equal to the molecular inertia. Comparing the molecular momentum or inertia of substances with those of water we obtain the specific heat of the substance. In other words the specific heat of (say) iron is the ratio between the quantity of heat necessary to raise the temperature of (say) one gramme of iron at 0° to 1° C. and the quantity necessary to raise the same weight of water from the same to the same temperature. Specific heat is not heat but number.

But if heat be molecular motion, how can the sun pour heat through space as free from ponderable matter as the space between the sun and the earth is known to be? Can there be some substance pervading space which has no weight and which can yet convey momentum for a hundred million of miles in such abundance that its mechanical effect on our planet is as great as that of a horse working its utmost on every square yard of the earth's surface? My own mind receives this notion with reluctance and distrust and not without pain.

Light, indeed, only exists in the radiant form, and although light may appear to do a vast amount of mechanical work, as when it raises an oak from an acorn, it does so not like heat, by putting its shoulder to the wheel, but by setting free imprisoned energies in the same manner as a little spark may cause the tremendous explosion of a powder magazine, a whistle may set an avalanche in motion, or a bugle call launch a squadron of cavalry. And accordingly the mind receives the hypothesis that light consists of the vibration of a nearly imponderable medium with less reluctance than is the case with radiant heat.

That the intensities of radiant heat and light falling upon a given surface vary inversely as the square of the distance of that surface from the radiant source is a geometrical rather than an experimental fact as soon as we admit that the medium through which the influence passes absorbs none of it, but that the influence or force diminishes only by dispersion or what I may call dilution by space.

The rules of reflexion and refraction enabled us to trace the fate of a light ray on striking the boundary surface between two media. We must conceive a visible body to be giving out light from all its points in all directions. If by catching a number of the light rays which one point gives out and either by reflecting them or refracting them we succeed in throwing them all together so as to cross one another in one point the second point is the focus of the first. If the same be done for the other points, the collection of foci so formed is the optical image of the original object. Such images falling upon the retina produce distinct vision. The eye is a compound lens partly solid and partly liquid and the surfaces of the various transparent parts

are of such curvature and the media of such refractive indices that the image of an external object is thrown precisely upon the retina.

I have followed as I always do with some reluctance the notion that white light "consists" of light of various colours. In an elementary course a teacher must be very chary of his own opinions when they are unsupported by those of others. But in this *causerie* I may state that I do not suppose that the various prismatic colours exist in the white light in the same sense even as oxygen, carbon and hydrogen exist in a piece of sugar but rather as a northerly and an easterly force may be said to exist in a north-easterly one and the latter to "consist" of the two former.

In studying frictional electricity we started with its mechanical manifestations. Conceiving all matter to be teeming with some indifferent electric fluid we concluded that this indifference resulted not from nullity but from neutralization; that electrical excitment is electrical decomposition and that the tendency which unlike electricities have to combine with one another gives rise to the phenomena of attraction. When neutral bodies are attracted by electrically exicited ones their neutral fluid is decomposed at a distance or by induction and the same amount of electricity may decompose an unlimited quantity of neutral fluid. We then examined the conducting powers of different substances and showed how electricity distributed itself upon conducting surfaces. If time had allowed we should have placed a magnetic needle near a wire which connected the prime conductor of an electric machine with the earth and noticed that the needle was moved.

Our first experiments with voltaic electricity seemed not to point to any relation between this and frictional electricity. Yet the wire connecting unlike metals dipped in one and the same cup of liquid which attacks one by preference was shown to deflect a magnetic needle in its neighbourhood. And if the unattached metal be fastened to the same end of the wire as that to which the prime conductor of the electrical machine was fastened the needle turns in the same direction in both cases, Accordingly as the prime conductor is said to have positive electricity a current of positive electricity is supposed to pass from the not-attached to the attached metal outside the liquid. This wire was found to have distinct magnetic properties. Folding it into a spiral form it became a magnet having poles and it gave its magnetism to soft iron. When the connecting wire was broken the current stopped unless the broken ends were connected by some conducting substance. Such substances were found to offer various resistances. Some (the metals) becoming red hot when thin, another (carbon) being bodily torn to pieces and carried with the current from pole to pole across an inch wide opening and giving rise in its passage to the electric light: others, like water being torn asunder most systematically into their constituent elements. We then briefly examined the mechanical relations between currents and proved that currents passing in the same direction attracted and those moving in opposite directions repelled one another. We also showed that a current set going along one wire established an induced current in a neighbouring wire. The phenomena of magnetism thus connected themselves almost spontaneously with those of galvanism: and a further study of the induced current showed in what intimate relation frictional electricity or high tension electricity stood to one and therefore to both.

Our last two meetings were devoted to Chemistry and I could of course but give a meagre account of this in the time. We saw however that Chemistry was the science of material combinations and decompositions and that although the force which urges the molecules of bodies to combine may be indentical with that which urges the heavenly bodies: yet the visible effects are different because we cannot trace the identity of the constituents after physical union has occurred. Further, it appeared, and surely this is a wonderful revelation, that the endless varieties of matter are made up of but few elements. I compared these elements to the few musical notes on a piano by arranging which in different sequences the countless emotions of music are produced. We turned finally to the examination of a few elements, namely those of air, water, and salt, and briefly noticed the chemistry of animals and plants.

I have sought throughout to avoid the use of the word "law," and I wish strongly that you should carefully clear your minds of the idea of there being anything in nature at all like the laws which men have contrived for the regulation of society. Certain deeds which are judged to be prejudicial to the well-being of the community are prohibited by a human law. Others which are deemed essential to that well-being are commanded. Punishment may be awarded to the doer of the one or the omitter of the other. But matter is a creature of impulse and

knows no other motive. What is called a natural law is accordingly nothing more than a recurrence of similar effects when the conditions are similar. It is based wholly on classification. Probably if I were to examine every plant of the natural order of the cruciferæ, I should find some oil containing sulphur in the seeds of all: and it would be a natural law that sulphur should be so found. This law would be, however, in its generality, and therefore wholly upset if a single exception were found, unless indeed the mind were so wedded to the association of sulphur and cruciferousness that the fact of the non-existence of sulphur were considered sufficient to exclude the plant from that order in spite of its other characteristics.

And now a few remarks of a more general kind:—

Since happiness should be the one great purpose of our lives, those things alone which bring it are worthy our esteem. And as such happiness depends upon our mental as well as our bodily well-being, a pursuit may earn devotion which either promotes material welfare or the culture of our faculties. In looking back upon the past I believe we all count those days the happiest in which our minds have received the greatest abundance of new truths. It is the pleasure, generally chiefly retrospective, which springs from such mental growth which causes many to regard their school days with great affection, which creates the love for *alma mater* in the student's heart, gives the indefinible charm to foreign travel, and is the secret of the rapture of music.

It would certainly be useless now-a-days to point out the relations which physical and chemical science have to our material well-being. Science is knowledge, and knowledge with the means and will to apply it is civilization. So I confine myself to speaking of the place which physical science should and must occupy in education.

Education is useless or worse than useless unless it ensures not only the gathering of facts with which to store the memory but also an insight into the ways and principles by which those facts are connected together and by the application of which they may be rendered useful. For it is then only that facts bear fruit and then only that they can be considered as truly in the possession of him who has acquired them.

And vast as are the material advantages which have been won for man by physical enquirers, and still more vast as are the benefits yet to be derived, I contend that the intellectual gain to the student is of far higher importance than either of these. One of the chief features which distinguish the experimental sciences is uncertainty. A great many operations made even in elementary text books admit of doubt. The cause of this is obvious. The enormous rapidity with which these sciences have grown and the extent of the field which they are destined to cover have put beyond possibility the verification of all the assertions which discoverers make and previous methods of research are often in a few years superseded. It is thus that great regions of physical science are comparable to newly discovered, thinly peopled, and imperfectly surveyed continents. Obvious as is the cause of this uncertainty, the consequence to the student if less obvious is of equal importance. Early made aware of the only approximate truth of the information acquired, he soon learns to trust with greater reliance to his own understanding. His judgment is brought into activity in a manner and a degree scarcely to be found in the cultivation of any other pursuit. Finding that even the most illustrious masters are liable to inexactness and error he learns to place great confidence upon the good faith of nature and the integrity of his own senses. The judicial faculty is also largely developed in another way by the cultivation of experimental science. To the student instances innumerable occur where the only information to be obtained is from the meagre accounts in books. Sometimes even this is wanting. Then the mind places before itself distinctly the difficulties which have to be overcome. It recalls from the store-house of the memory, or from books, cases parallel or to the point and it passes in review the things, properties and appliances at its disposal. When at last the experiment is made, unforeseen factors may render it futile. The perception of how and why the failure happens leads, through the judgment, to the removal of the causes of failure—to success. For having faith in the truth that the same things under the same circumstances will always produce the same effects, when he sees unlike effects produced he feels assured that there must be a sufficient cause for this difference and the efforts to discover and remove this, form one of the most beneficial influences to which the growing mind can be subjected.

Further, the student feels that similar things under similar circumstances will produce similar effects. In this way the spirit of physical prophecy is fostered. We learn to predict, and

though these predictions are often overthrown by the actual results obtained, such overthrow produces humility rather than humiliation. For it is accompanied by the remembrance of the promise which nature is every day giving, "Ask me rightly and my answer will be true." The satisfaction arising from the fulfilment of what may be considered as a physical prophecy is scarcely greater than that of the discovery of the reason why such prophecy is not fulfilled. And the gratification felt by the mind in both cases is one of the highest and purest emotions which man can know.

Sometimes it has, however, been actually made a subject of reproach to a science that it is experimental; and it is compared to its disadvantage with such an exact science as Astronomy. But let us imagine that the power of the Astronomer were so augmented that he too could play experiments. Let us suppose him to have been capable of altering at will the size, shape and distances of the heavenly bodies. We should not then have had to wait for thousands of years before we were convinced of the rotation of the earth, nor for hundreds of years after that for the discovery of the law of gravitation. An experimenter must not therefore be looked upon as one groping blindfold and thwarted and confounded at every turn by unexpected results: but rather as one armed by the experience derived from observation and previous experiment, resolutely but circumspectly entering the unexplored forest of facts, urged sometimes only by the restless spirit of discovery, sometimes by the ambition of earning the honourable reputation of a pioneer, but sure always that his observations, if faithfully recorded, will aid the future traveller.

How great then is the responsibility of one who records his travels in the unknown regions of experimental science. By what name can we stigmatize one who forges or garbles an account of scientific discovery? He can only be compared to the imposter who brings back, from an unknown land, false accounts of fertile plains and generous rivers, reckless that his mis-statements may be the waste of the lives of those who, trusting to his worthless word, may set out for the promised land. And how careful every discoverer in science should be not only to shun wilful mis-statements but accurately to note and painfully to describe the minutest circumstances attending these experiments: that those who follow in his footsteps may not be disheartened by want of success or disgusted by the suspicion of want of integrity in the original discoverer.

The qualities of patience and perseverance, two of the most precious properties which we possess, are cultivated in the most eminent degree by the study of Physics and Chemistry. No genius, no dash, can supply the place of these, without them, glimpses into new fields may be obtained, but neither can they be surveyed nor the fruit of their abundance gathered.

The very unlimited nature of the science forms a most wholesome discipline to the mind. There are many sciences of undoubted importance which can as yet be wholly grasped by a single mind. And the masters of such sciences are in a position to coordinate new facts as they are presented. But the literature of physical facts forms a library. From every civilized country news is reaching us of new and important discoveries. And it is not the least of the advantages of the successful study of Chemistry that it necessitates the acquirement of the more important of the modern languages. For the periodicals in which recent discoveries are registered are seldom translated in full into any one language, and it takes a long time before the new facts are incorporated into the literature of any one country.

Every new truth is indefinitely prolific. It may lie for a long time dormant until it finds a congenial soil and an appropriate climate. Every observation is a substantial gain in the cause of civilization. For the one explorer starts from the point where the other left off, so that every step which the second comer makes beyond the footsteps of his predecessor is an advance and a gain. While therefore the canvas of the most illustrious painter perishes, while the usefulness of the sculptor is scarcely more enduring than the marble in which his chisel has wrought, a fact brought to light from the dark regions of the physical world lives for ever, embodied in subsequent disocoveries which it has helped to call forth, and which embrace and embody it through all time.

If the material well-being of mankind is thus furthered by a knowledge of physical and chemical laws: if the acquirement of these laws and their application form a wholesome discipline for the mind: the reward of one who has made himself acquainted with these Sciences is indeed great. For him the world is full of harmonies to which the ears of others are deaf. He can breathe with more satisfaction when he knows why he breathes. He can eat his

food with greater pleasure when he knows the aim of eating and the destination of the various substances which he puts into his mouth. He can warm himself at the fire-side with infinitely greater satisfaction when he can see in the glowing embers, not merely the fantastic forms of the dreamer, but the working of a principle, the link of a chain of principles by whose means the earth is made a glorious planet.

Let it not then be supposed that any one has a right to refuse scientific knowledge to those entrusted to his charge for education Let it not be imagined that ignorance of the properties of matter can be indulged in with impunity by creatures whose great aim is to adopt matter to their own wants. Let us not allow our children to grow up in ignorance of the world which they inhabit; but, being themselves matter, and living in a material world, let us give them a chance of knowing themselves and their relation to the outer universe.

They will thus assuredly satisfy themselves that there is about us a method of which most are ignorant. They will see Cosmos where most see only Chaos. By the knowledge which they will get they will become humble in their increased wisdom, and happy in their increased humility.

To the student of nature one thing becomes for ever more and more clear: that she is faithful. When her answers to our questions are ambiguous it is because we are dumb to the meaning of her words; when they are meaningless it is because she interprets our questions, not in the distorted language in which we propound them, but in the language of truth, of which we know not the syntax. Her one refrain is this: be truthful and you shall know the truth. As children without guile let us question her, as a mother without guile will she reply. Let us therefore look upon the world of matter and of force, not as the slave of our ambition, nor as the handmaid of our comforts. Let us neither regard it as the pitiless tyrant reminding us by the prison and the lash of our weakness, nor as a monster of shapeless terror watching and destined to devour us. But let us love it as the friend of our childhood, honour it as the companion of our prime, and trustfully cling to it as the stay of our old age.

F.G.